

clusters in a gas stream, then focus a laser on the particles. Those clusters with energy levels that resonate with the laser should be knocked out of the batch and can later be deposited on a substrate. "It's highly speculative," Vahala acknowledges. "But over time, crazy things become doable."

Another avenue taken by Kash at Bellcore takes advantage of the stress and resulting deformations created when one material is grown on top of another in a specific pattern. "Normally you don't want stressed materials," she adds. But in a jujitsu maneuver, she began purposely stressing materials to create lower band-gap regions—and so form quantum dots.

Most workers nonetheless continue to try to exploit lithographic techniques—but with twists. At AT&T, Henryk Temkin is making dots with different semiconductor compounds—indium phosphide and indium gallium arsenide, which emit a frequency of light that can be transmitted over optical fibers with little attenuation. Moreover, by containing all the fabrication steps within a single, high-vacuum environment—a trick pioneered by Hayaishi's team—Temkin reduces the possibility of contamination and produces better-quality dots.

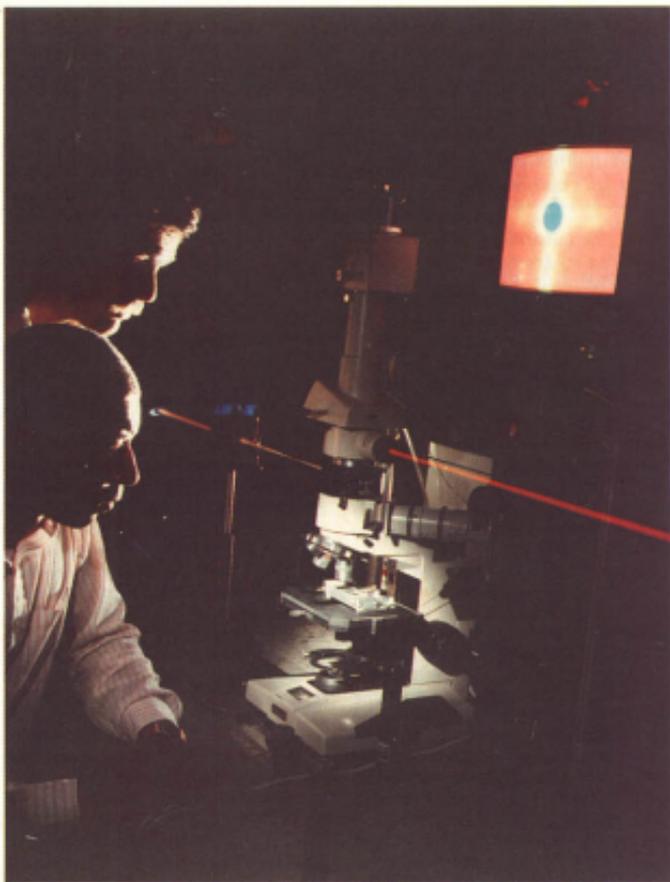
At many other universities and companies, researchers are honing their skills in etching the small devices. Among the groups singled out in the field as having achieved highly promising results are teams at the University of Glasgow, Delft University in the Netherlands and Texas Instruments.

Two years ago at TI, Reed and Randall successfully made a single quantum dot. Because it was isolated from any other device, the dot "wasn't useful, but it worked," Reed says.

Schemes for connecting an array of dots into a larger circuit or system have remained elusive. "You could make clusters electrically active by contacting them with a conducting polymer," Steigerwald muses. "That's not quite science fiction, but it's in the future."

Randall continues to explore electrical links. "My biggest headache," he grouses, "is making good contacts to quantum dot posts." If he succeeds, he and his colleagues will try to employ each dot in an array as a computing element. Because each dot can have multiple energy states, one dot could replace several conventional transistors.

Such dots might also enable the TI team to try out a novel interconnection scheme called cellular automata. Instead of connecting transistor dots one after another in a series, every dot would talk to only four of its nearest



LIGHT FROM KRYPTON ION LASER (left) excites a quantum well surface-emitting laser (on microscope stage), which emits an infrared beam (right) in this experiment at Sandia National Laboratories. (The infrared beam has been made visible by running the light through an optical conversion material.) A television monitor displays a cross-sectional profile of the beam from the surface-emitting laser.

neighbors. By contacting the dots on the edges of the array, it should be possible to trigger the operations of inner dots. This would transform the circuit into a massively parallel system in which many transistors operate simultaneously rather than sequentially.

Although this architecture would be inefficient with today's transistors, it might make sense with quantum dots that are more than a single switch, Randall suggests. "Downscaling will continue, and eventually it's going to crush down to dots," he says. "We'll need interesting [dot] coupling designs when we get there."

Just when workers will "get there" re-

mains uncertain, and time is growing short. Those building telecommunications networks are demanding more efficient lasers for pumping additional data across the lines. Chip makers worry that the ability of conventional lithography to pack more devices onto a chip will stall by the end of the 1990s. That, points out Robert E. Nahory, who manages Bellcore's semiconductor materials research, makes now "the time for innovation."

With reporting by correspondent Tom Koppel in Tokyo.